Load balancing challenges in AI fabric

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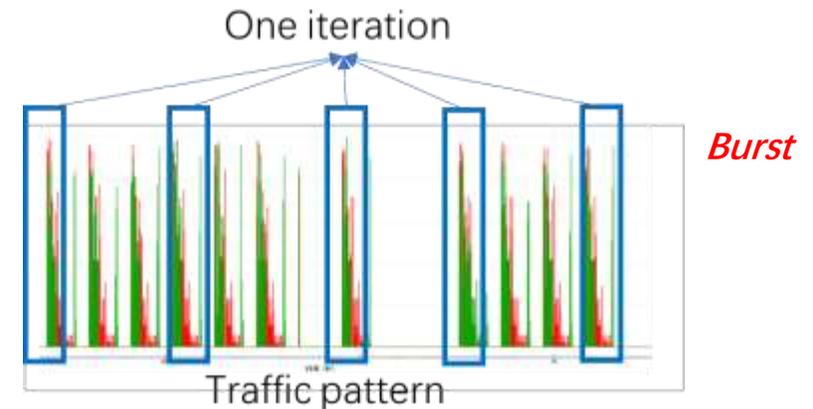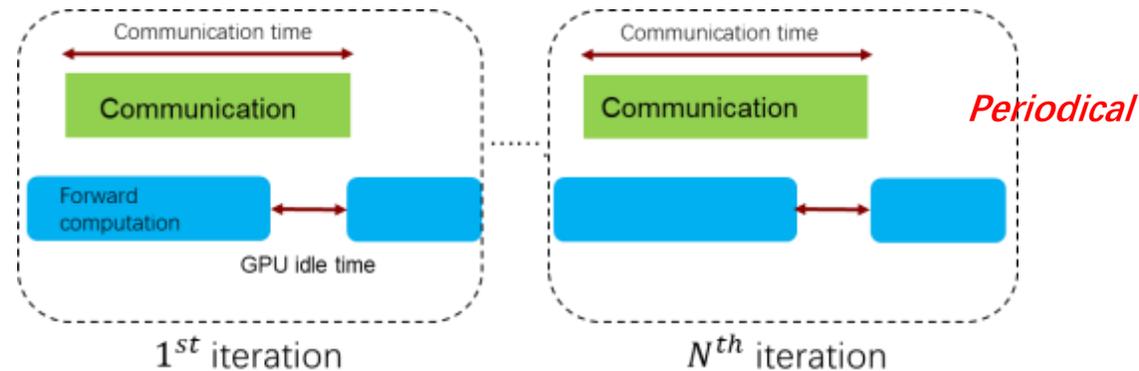
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AI Traffic pattern challenge

Traditional DC Traffic pattern

- Many asynchronous small BW flows.
- Chaotic pattern averages out to consistent load.

AI (All-to-all Collective) Traffic Pattern

- Few synchronous high BW flows.
- Synchronization magnifies long tail latency and bad load balancing decisions.

Data from Cisco's public whitepaper.

Traditional flow-based LB perform poorly

- **Flow-based load balancing means switches distribute packets to multiple paths in the flow granularity, and Packets within a flow take the same forwarding path.**

- **The inherent drawback of flow-based LB is its coarse granularity:**
    - It does not take into account the size of different flows;
    - Especially in AI fabric, it's hard to balance the few and high bandwidth flows well.
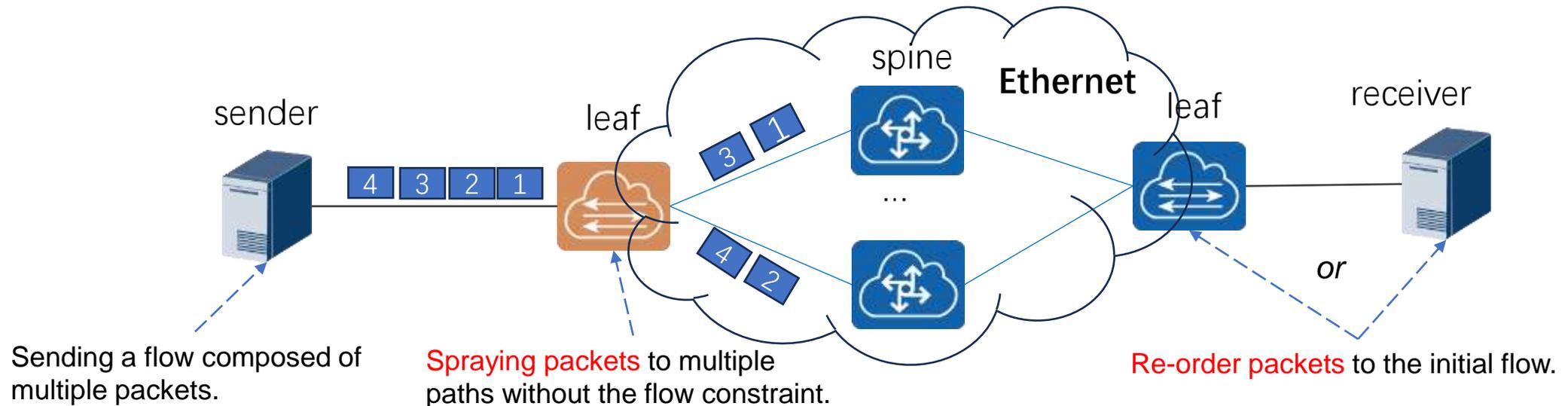
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switch   100   switch

60   100

60
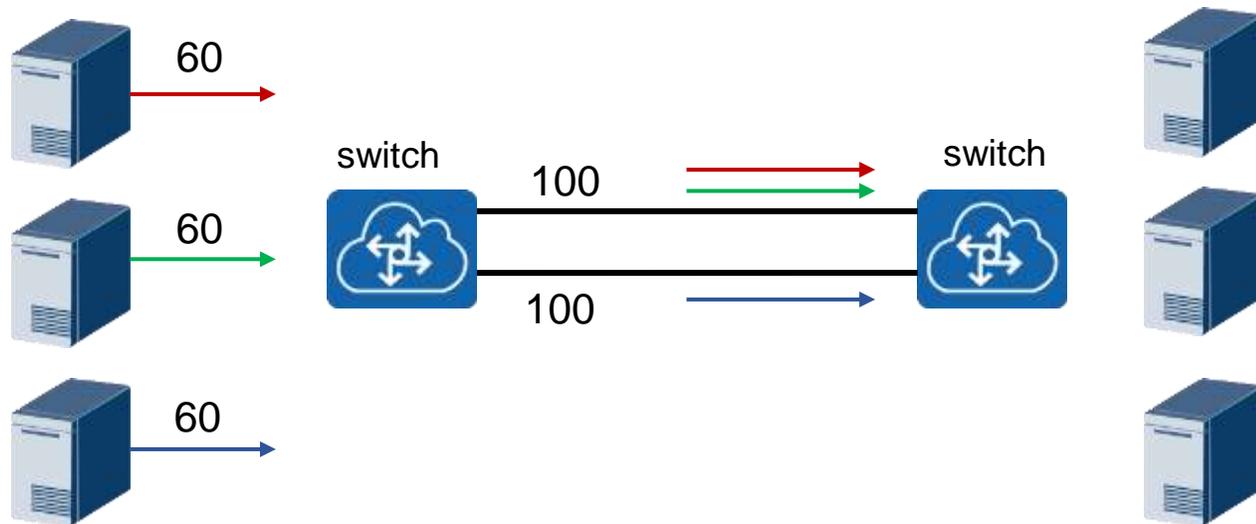
Example
- When the number of flows is not divisible by the number of available paths, it's impossible to get a optimal balance using flow-based LB.

# Packet-spray-based LB become the trend for AI fabric (1)

- **Packet spray means switches distribute each packet to multiple paths independently, making the load on the network more balanced than flow-based.**

- **There are several routes supporting packet spray:**
  - Cell-based in dedicated network or ethernet-based: Standardization → ✓ **Ethernet-based.**
  - NIC-driven or Network-driven: Applicable to different scenarios. → Focus on **network-driven** solution in this document.

- **Basic Architecture of network-driven packet spraying in ethernet:**

Sending a flow composed of multiple packets.

Spraying packets to multiple paths without the flow constraint.

Re-order packets to the initial flow.

Packet-spray-based LB become the trend for AI fabric (2)

- **We conduct an experiment to evaluate the performance of flow-based and packet-spray-based LB.**

Experiment settings
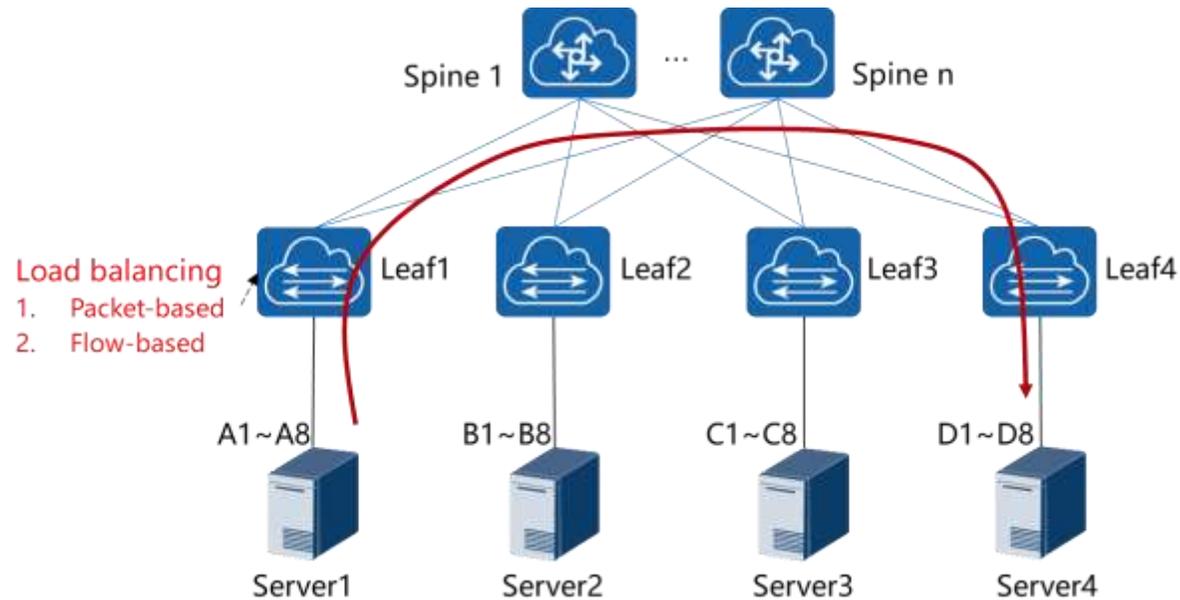
Results
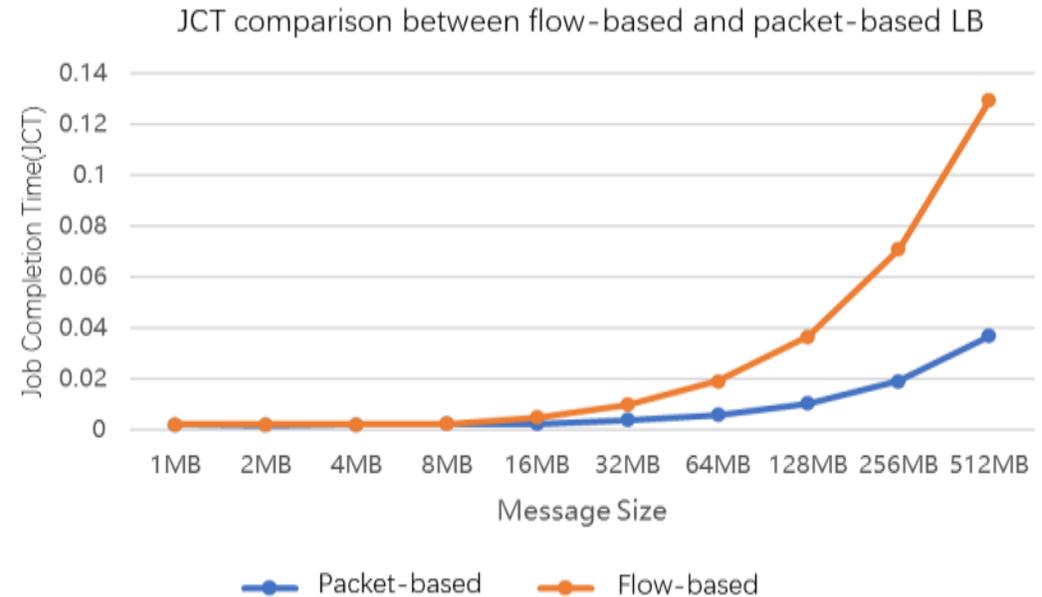
- The topology is the classic two-layer clos network, 4 servers, 8GPU with 8 NICs in a server.
- There are 8 jobs running: A1~D1、A2~D2….A8~D8.

- Testing the task completion time (JCT) of flow-based and packet-spray-based load balance under different message size.
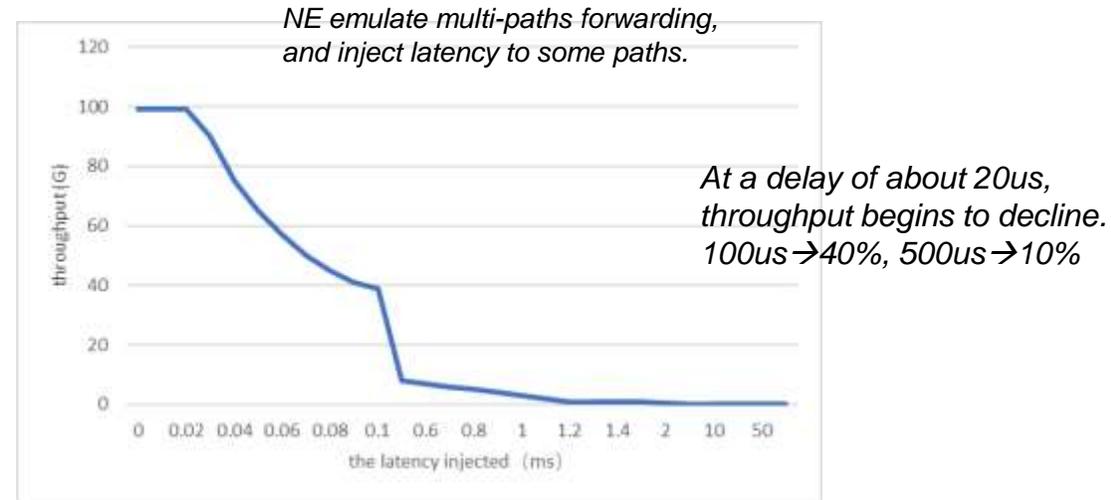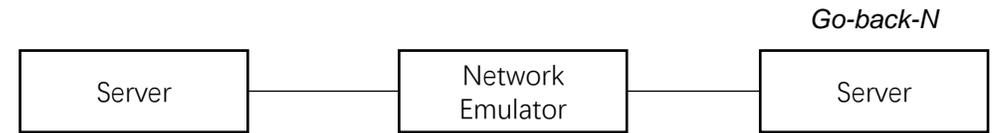- In a 512MB scenario, JCT of packet-spray-based LB is reduced to about one-third compared to flow-based.

Challenges in Packet-based LB

- **The main side-effect of packet-spray-based LB is causing packets of a flow arriving at receiver out of order:**
  - Re-order problem.
  - **Reliability problem: Loss-detection and retransmission;**

- **Out-of-order cause performance degradation significantly under Go-back-N mechanism.**
  - The mainstream RNIC adopt Go-back-N mechanism to provide reliability.
  - A lot of out-of-order packets may trigger frequently Go-back-N, resulting in a precipitous decline in throughput, as shown in the right emulation.

Go-back-N

NE emulate multi-paths forwarding, and inject latency to some paths.

At a delay of about 20us, throughput begins to decline.
100us→40%, 500us→10%

- **RNIC can adopt Selective ACK to improve GO-back-N, but still existing problems hindering performance.**
  - The receiver can not directly determine whether the packet is lost or just out of order through the PSN,
  - relying on the timeout mechanism to detect packet loss reduces the sending rate.
 - Accurate fast-retransmit is necessary, but only by receiver is often not possible.

- **A preliminary conclusion is that processing out-of-order packets exclusively on the receiver NIC can hardly achieve optimal performance.**

Network can do more...

- **In packet-spray-based LB, the root difficulty of receiver dealing with out of order packets is that it does not know the forwarding path and state of each packet.**

- **An intuitive solution is that network provide receiver the path information of packet forwarding to help loss detection and fast retransmission.**

Key idea: network device insert the path information(e.g. Path ID) into packet header, so that the receiver can detect the loss more quickly and execute fast retransmission.

Example
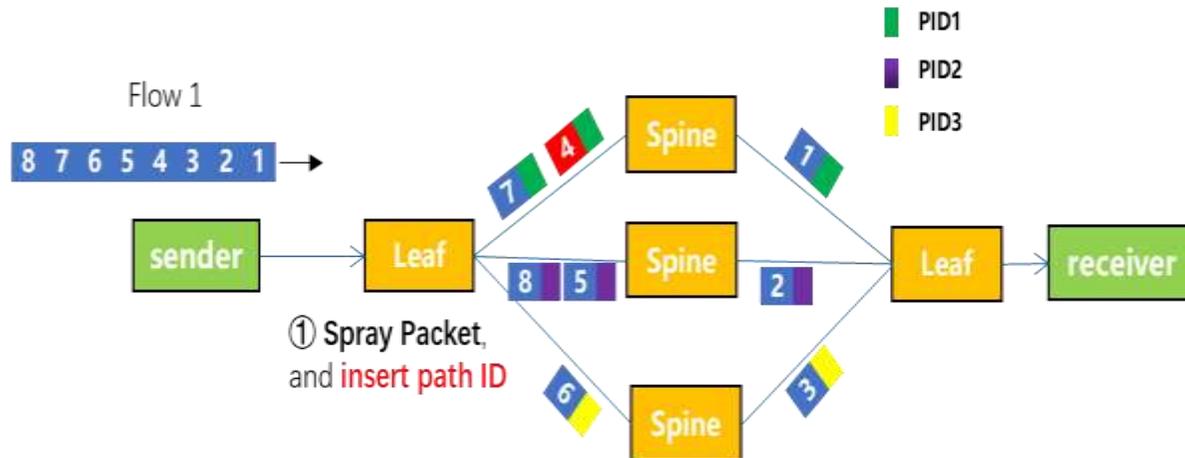
② Update the receiving window of flow 1, *assume the 'hole' is packet 4*:

PSN	1	2	3	4	5	6	7	8
state	1	1	1	0	1	1	1	0

③ Update the max receiving PSN of each path of flow 1:
- Path 1: maxRcvPSN[1]:7
- Path 2: maxRcvPSN[2]:5
- Path 3: maxRcvPSN[3]:6

④ Compare the hole number with maxRcvPSN of each path:
- If hole number < maxRcvPSN of all paths → Packet 4 loss

Flow 1

8 7 6 5 4 3 2 1 →

sender → Leaf → Spine / Spine / Spine → Leaf → receiver

① Spray Packet, and insert path ID

PID1
PID2
PID3

Current industrial support for packet-based LB

① **Cisco：Silicon one**

- *"An alternate solution is to use a fully scheduled fabric to connect the GPUs. This approach <mark>sprays packets</mark> across all links and reoders the packets at the exit, so no network congestion builds up. Simply put, it allows for an ideal interconnect under all traffic conditions."*
- Solutions - Cisco Silicon One Product Family White Paper - Cisco

② **Broadcom：Tomahawk 5**

- *"It supports both <mark>per-packet spray</mark> and flowlet modes of operation and can be enabled selectively for different traffic types with ineligible flows falling back to hash-based ECMP. DLB is successfully deployed in multiple networks today."*
- Cognitive routing in the Tomahawk 5 data center switch (broadcom.com)

③ **Juniper：Junos OS**

- *"<mark>Randomly sprays the packets</mark> to the aggregate next hops to ensure that the next hops are equally loaded resulting in packet reordering."*
- Per-packet random spray load balancing | Juniper Networks Pathfinder Feature Explorer

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- **The mainstream chip venders （Cisco、Broadcom、Nvidia..） have supported the packet spraying to balance load, but their solutions are different. → standardization of packet-spray-based load balancing on ethernet is needed.**

Summary

- **Introduce the drawbacks of traditional flow-based ECMP for AI fabric, and packet-spray-based load balancing become the trend.**

- **Analyze the challenges bring to receiver in packet-spray-based load balancing.**

- **Network can assist receiver to solve the challenges.**

- **Potential Standard Requirements:** Need to standardize path information in L2 for network-assisted fast retransmission, such as path ID.

Next Action

- **Propose a Study/Work Item：** Packet-Spray-Based AI Fabric

- **Scope：** Packet-Spray-Based Load Balance 、Packet-Spray-Based Congestion Control、Reorder、Ethernet QoS、Telemetry、high-precision OAM、Protection etc.

Thank You !